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The role of smart data in smart home: health monitoring case

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Abstract

The smart data continuum refers to a series of increasingly semantically expressive definitions for data elements. With increased semantics we can achieve semantic interoperability, i.e., the ability of computer systems to exchange data with unambiguous and shared meaning. In context of smart homes it offers advanced connectivity of devices, systems, and services that goes beyond machine-to-machine communications. In order to achieve semantic interoperability in smart homes we have developed Smart Home Ontology, which gives semantics for the data that are exchanged by the systems and devices in a smart home. From technology point of view, we have studied the combination of cloud computing and Internet of Things as they enable ubiquitous sensing services and powerful processing of sensing data streams beyond the capability of individual "things", thus stimulating innovations in both fields. Further, we will show how the principles of the Linked Data allow the integration of Smart Home data with other data sources, and thus increases the usability of Smart Home data. In particular we have restricted on health monitoring data.

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Keywords: Smart data; RDF; Ontologies; Health monitoring; Semantic interoperability; Internet of things

1. Introduction

A stovepipe system is a computer system where all the components are hardwired to only work together[1]. So the term stove pipe system evokes the image of stovepipes rising above buildings, each functioning individually. The information only flows in the stovepipe and cannot be shared by other systems or organizations that need it.

The systems of a smart home should not be stovepipe systems. In a smart home there are many functions that can only be achieved by functioning together – among themselves or with external systems. Through functioning together we can also achieve synergy, i.e., we can achieve outcomes that would not be achievable in working independently.

The notion of smart data is a key for breaking down stovepipe systems[1]. It refers to data that is application-independent, and part of a larger information ecosystem. Further, the smartness of data can be classified by a series of

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increasingly semantically expressive definitions for data elements, which are also called as smart data continuum and ontological spectrum. At the low end of the continuum is a simple binding of a single word and its definition while at the high end is a full ontology that specifies relationships between data elements[2]. With in-creased smartness we can achieve increased precision and semantic interoperability between communicating systems. As smart houses are comprised of a variety of communicating systems and tools, smart data should have a key role in the systems of smart homes.

Resource Description Framework[3] (RDF) is a key for representing smart data. It is not a data format, but a data model with a choice of syntaxes for storing data files. In RDF we can express facts with tree-part statements known as triples. The subject identifies the thing being described, predicate is a property name, and object is property value. So, each triple is like a little sentence that states a fact.

However, RDF in itself does not bring smartness. It depends on the expression power of the used vocabulary. By a vocabulary we refer to a set of ontologies, which specifies the used terms and their semantics. Shared ontologies provide the ability of two or more systems to exchange information and to use the information that has been exchanged[4].

We have developed an ontology, called Home Ontology, which gives the semantics for the data that are exchanged by the systems and devices of a smart home. We have also adapted the principles of the Internet of Things (IOT) in connecting the IOT devices of a smart home. By IOT devices we refer to the inter-connection of uniquely identifiable embedded computing devices within the existing Internet infrastructure. It is expected to offer advanced connectivity of devices, systems, and services that goes beyond machine-to-machine communications and covers a variety of protocols, domains, and applications.

In a smart home IoT devices can be used to monitor and control the mechanical, electrical and electronic systems, e.g., to control lighting, heating, ventilation, air conditioning, appliances, communication systems, entertainment and home security devices to improve convenience, comfort, energy efficiency, and security. They also suit well for remote patient monitoring where monitoring devices can range from blood pressure and heart rate monitors to advanced devices capable of monitoring specialized implants. Specialized sensors can also be equipped within living spaces to monitor the health and general well-being of senior citizens, while also ensuring that proper treatment is being administered. Other consumer devices to encourage healthy living, such as wearable heart monitors, are also a possibility with the IoT.

It is also turned out that interesting challenges arise when IoT meets cloud computing[5]. The combination of cloud computing and IoT can enable ubiquitous sensing services and powerful processing of sensing data streams beyond the capability of individual “things”, thus stimulating innovations in both fields. For example, cloud platforms allow the smart sensing data to be stored and used intelligently.

Further the ability to share patient’s health data stored in clouds promotes the introduction of new emerging healthcare trends, such as patient-centered care. It emphasizes the coordination and integration of care, and the use of appropriate information, communication, and education technologies in connecting patients, caregivers, physicians, nurses, and others into a healthcare team where health system supports and encourages cooperation among team members.

The rest of the paper is organized as follows. First, in Section 2, we introduce the notion of knowledge centric smart home, and its cloud-based implementation. Then, in Section 3, we restrict to remote health monitoring: we describe how cloud-computing can be exploited in practicing patient-centered remote health monitoring. In Section 4, we deal with aspects of smart data: first we deal with ontology engineering in modeling smart data, and then we present the principles of the Linked Data, as well as their adaption to smart homes. We also illustrate the use of RDF in representing smart data. Finally, Section 5 concludes the paper.

2. Knowledge-centric smart home and cloud computing

Information integration and sharing are the key concept in any society, organization, as well as in smart homes. Knowledge management is a discipline which considers information: it concerns with acquiring, accessing and maintaining knowledge within an organization[1]. It refers to a multi-disciplined approach to achieving organizational objectives by making the best use of knowledge.

We have adapted the idea knowledge centric organization to smart home: we have revolved all the applications of the smart home around the shared Home Ontology, which integrates, and gives the semantics for the data items of the smart home data repositories (Fig. 1). This cloud-based integrated repository includes welfare data repository, lighting control data repository, heating data repository, ventilation data repository, air condition data repository, entertainment data repository, and security data repository. These repositories receive their data from the IoT devices located in smart home while the users access the repositories through repository specific applications.

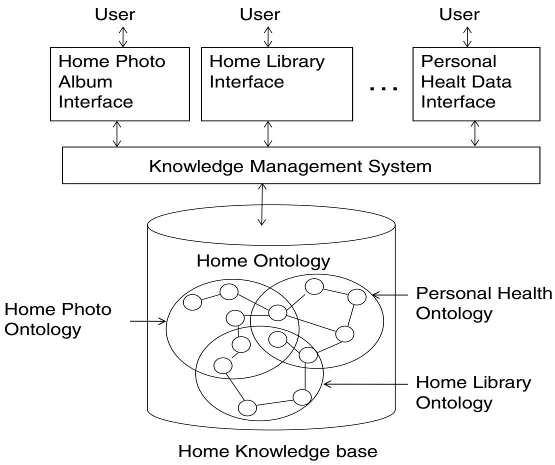

Fig. 1. The main components of the knowledge centric smart home system.

Cloud computing represents new way of delivering home information technology: anyone with a suitable Internet connection and a standard browser can access an application in a cloud[6]. Thus cloud computing allows smart homes to use applications without installation. It also allows for more efficient computing by centralizing storage, memory, processing and bandwidth[7]. Further, unlike traditional hosting it provides the following useful characteristics:

- The resources of the cloud can be used on demand, typically by the minutes.
- The used resources are easily scalable in the sense that users can have as much or as little of a service as they want at any given time.
- The resources are fully managed by the provider. The consumer does not need any complex resource, only a personal computer with internet access.

Software as a service (SaaS), is a type of cloud computing, which is suitable for our purposes. In this service model, a service provider licenses an application to customers either as a service on demand, through a subscription, in a "pay-as-you-go" model, or at no charge[8]. The SaaS model to application delivery is part of the utility computing model where all of the technology is in the "cloud" accessed over the internet as a service.

There are various architectural ways for implementing the SaaS model including the followings[8]:

- Each customer has a customized version of the hosted application that runs as its own instance on the host's servers.
- Many customers use separate instances of the same application code.
- A single program instance serves all customers.

In the case of smart homes the required computation is rather small compared with traditional business applications, and thus the last mentioned architecture is appropriate for the implementation of smart homes, i.e., a single system serves all smart homes. However, home specific data can only be accessed by the users that are authorized by the smart home owner.

3. Health monitoring

Remote health monitoring is a technology to enable monitoring of individuals outside of conventional clinical settings (typically in homes), which may in-crease access to care and decrease healthcare delivery costs[9]. It uses telecommunication and information technologies in order to provide clinical health care at a distance[10]. So, it aims to eliminate distance barriers and can improve access to medical services that would often not be consistently available[11].

3.1. Traditional health monitoring systems

From technology point of view remote monitoring systems consist of a hub and wireless peripheral devices that collects physiologic data[12]. Typical peripheral devices include blood pressure cuffs, pulse oximeters, weight scales, and blood glucose meter. The data gathered from peripheral devices are transmitted by the hub to a clinical database for later analysis (Fig. 2). In this architecture the hub and the database represent an IOT device.

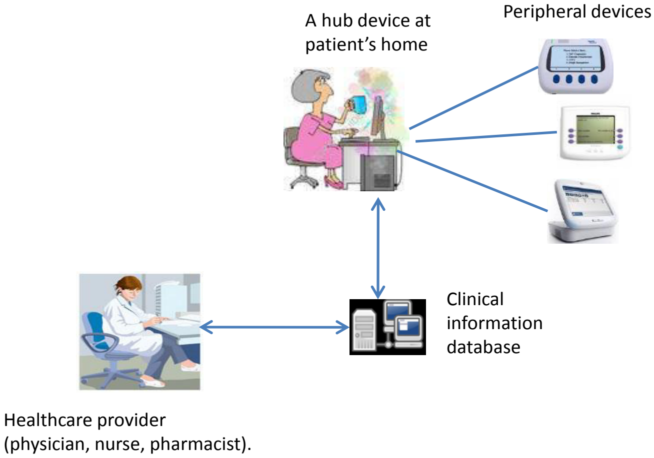

Fig. 2. Remote monitoring through a clinical information database.

3.2. Patient-centered remote monitoring

The technology that supports patient-centered care[13] has to coordinate the flows of information that are coming from a variety of sources. These information flows include:

- Health regimen information between healthcare providers (physicians, nurses and pharmacists).
- Healthcare information between healthcare providers and patient's family members.
- Relevant educational health information from healthcare providers to patient.

Supporting these information flows is much more challenging as the simple vital sign information flow that characterized an earlier generation of remote patient monitoring. In particular the traditional remote monitoring model illustrated in Fig. 2, supports only partially these requirements as the usage of the clinical information system is isolated from third parties such as from patient's family members.

The cloud-based health monitoring system architecture, which also supports patient-centered care is presented in Fig. 3.

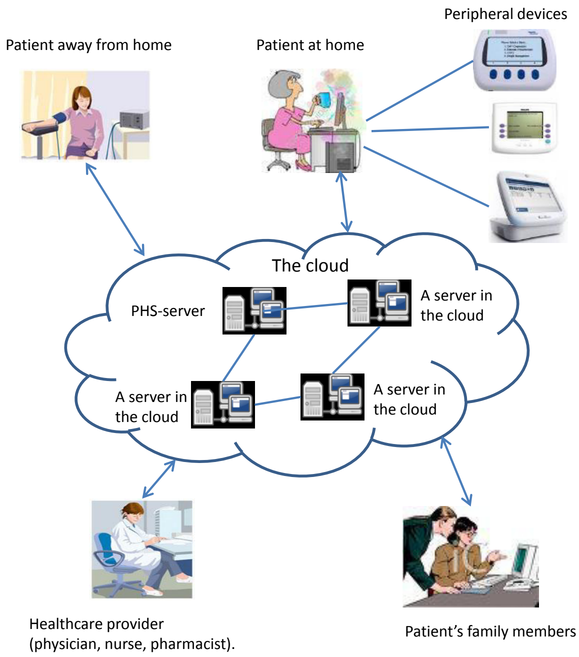

Fig. 3. The users of the cloud-based health monitoring system.

We next itemize some clarifying aspects of the figure:

- The user accesses a service in a cloud, which in turn may interoperate with other services provided by third parties.
- The patient accesses his or her health data stored in cloud through the browser. As the patient needs nothing but an internet access, the patient can easily connect to the cloud at home, as well as being away from home.
- Healthcare providers and patient's family members that are authorized by the patient can access patient's health data as well as communicate through their browsers.

4. Smart data engineering

4.1. Ontology engineering

In the context of computer science, an ontology is a general vocabulary of a certain domain, and it can be defined as "an explicit specification of a conceptualization"[14]. It tries to characterize that meaning in terms of concepts and their relationships[15]. It is typically represented as classes, properties, attributes and values. As an example, consider a subset of our designed Welfare Ontology presented in Fig. 4.

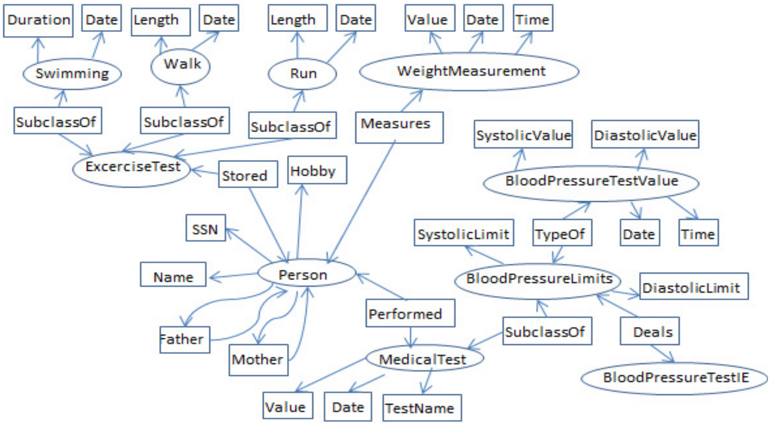

Fig. 4. A graphical presentation of a portion of the Welfare Ontology

In this graphical representation ellipses represent classes and subclasses while rectangles represent data type and object properties. Classes, subclasses, data properties and object properties are modeling primitives in OWL[16] (Web Ontology Language) Object properties (e.g., Measures) relate objects to other objects while data type properties (e.g., Name) relate objects to datatype values. In Fig. 4 we have presented only a few of objects' datatype properties.

Fundamentally the Welfare Ontology comprises the vocabulary that a person can use in describing his or her personal welfare information. Hence we do not assume that a person uses all the terms of the vocabulary (ontology). For example, datatype properties Father and Mother are included in the vocabulary, but the person does not have to give values for these properties. Neither the person needs class Swimming, if swimming is not included in his or her hobbies.

4.2. Using Linked Data in connecting repositories

Linked Data provides a way to integrate the data of the Welfare Ontology with other ontologies, which in turn enables synergy. In particular, linking the Welfare ontology with Personal Health Record (PHR) Ontology expands the usability of the both ontologies.

Linked Data is not a specification, but rather a set of best practices for providing a data infrastructure that facilitates to share data across the web[17]. It allows the use of semantic web technologies such as RDF, OWL and SPARQL[17] to build applications around that data.

Tim Berners-Lee coined the term Linked Data, although the idea is very old and is closely related to concepts including database network models, citations between scholarly articles, and controlled headings in library catalogs.

The four principles of linked data are the followings[17]:

1. Use URIs to denote things as they are the best way of available to uniquely identify things, and so to identify connections between things.
2. Use HTTP URIs so that these things can be referred to and looked up by people and user agents.
3. When someone looks up a URI, provide useful information leveraging standards such as RDF, RDFS, and SPARQL. RDFS and OWL allow to spelling out a list of terms and information about those terms and their relationships in a machine readable way, e.g., for SPARQL queries.
4. Include links to other related things (using their URIs) when publishing data on the Web. So applications can follow these links, and thus discover interesting new things.

Note that the term Linked Open Data is becoming popular as the amount of freely available public data is increasing. However, sharing web pages among the employees behind company's firewall, without making those web pages accessible to the outside world, has also proven to be useful.

Our way of leveraging Linked Data is neither based on freely available public data nor web behind company's firewall but rather on the data that is available for the members of the smart home.

Naming the links between web pages of the smart home community requires the development of an appropriate vocabulary. We have presented the vocabulary in OWL, and it is called Link Ontology as it provides a vocabulary for naming the links. The Link ontology is graphically presented in Fig. 5. The Link Ontology presented here is just a starting point: it will evolve over time from its original version as the need for new types of links arises.

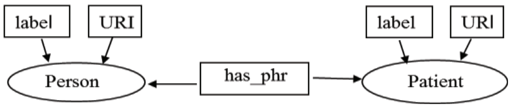

Fig. 5. The Link Ontology.

The function of the object properties in the Link Ontology is to integrate ontologies. That is, the classes of the Link ontology are originated from different domain ontologies, which in our case are the Welfare Ontology and the PHR Ontology: class Person in the Link Ontology originates from the Welfare Ontology, and class Patient originates from the PHR Ontology, which is graphically presented in Fig. 6.

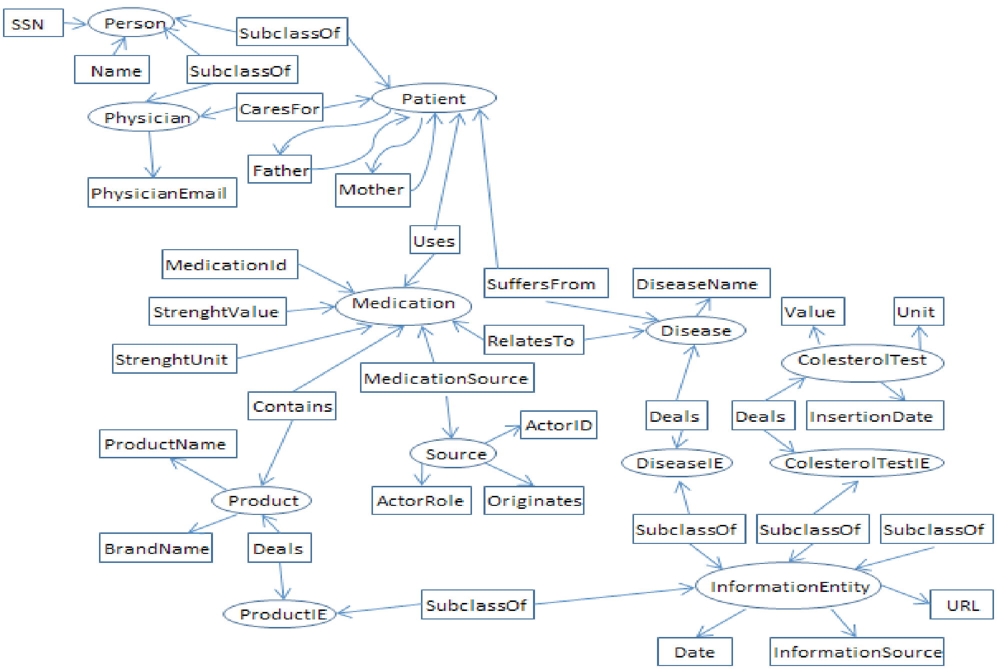

Fig. 6. The PHR Ontology.

The PHR Ontology is derived from the XML schema of the CCR standard. The CCR standard is an ANSI-accredited health information technology standard, which is published in 2006[18]. Though it is proposed for PHRs its original purpose is to enable the creation, storing and exchange (between computer systems) of digital summaries of individuals' administrative and clinical health information.

In transforming the XML schema of the CCD file to OWL-ontology we have used on the whole the following rules:

1. The complex elements of the XML-schema are transformed into OWL classes.
2. The simple elements of the XML-schema are transformed into OWL data properties such that the complex element is the domain of the da-ta properties.
3. The attribute of the XML-schema are transformed into OWL data properties.
4. The relationships between complex elements must be named and transformed to OWL object properties.

4.3. Searching multiple datasets by SPARQL

The name SPARQL is a recursive acronym for SPARQL Protocol and RDF Query Language, which is described by a set of specifications from the W3C[19]. SPARQL Protocol refers to the rules for how a client program and a SPARQL processing server exchange SPARQL queries and results.

A SPARQL query specifies the pieces of information that meets the stated conditions. The conditions are described with triple patterns, which are similar to RDF triples but may include variables to add flexibility in how they match against the data. There is also a variety of SPARQL processors (also called SPARQL engines) available for running queries against data both locally and remotely. SPARQL pro-vides two ways for querying remotely: using FROM keyword or using SERVICE keyword. In the former way the FROM keyword names a dataset to query that may be local or remote file. In the latter way, instead of pointing at an RDF file somewhere, a SPARQL endpoint is pointed. A SPARQL endpoint is a web service that accepts SPARQL queries, runs the queries, and then returns the result.

In addition, SPARQL allows searching multiple datasets with one query. Hence, although the data sets of the Welfare Ontology and PHR Ontology are located in different servers, we still can query those data sets within one SPARQL query. For example, processing the query "Give me Mary's ongoing medication when her weight had a minimum value" requires to retrieving data from the Welfare Ontology and the PHR Ontology.

RDF's modeling primitive is an object-attribute-value triple, which is called a statement[3]. In order that RDF data can be represented and transmitted it needs a concrete syntax, which is given in XML, i.e., RDF statements are usually coded in XML. Hence, RDF inherits the benefits associated with XML. However, other syntactic representations (e.g., Turtle[20]) are also possible, meaning that XML-based syntax is not a necessary component of the RDF model.

One RDF description may contain one or more RDF statements about an object. For example, in Fig. 7, the description concerning Mary Taylor's weight measurement (identified by "weightmeasurement100820151028") contains five RDF statements: the first states that its type in the Welfare Ontology is Weight-Measurement, and the second states that it measures Mary Taylor.

```
<rdf:RDF
   xmlns : rdf=”http://www.w3.org/1999/02/22-rdf-syntax-ns#”
   xmlns : po=http://www.helsinki.fi/Welfare_Ontology#>
      <rdf:Description rdf:about=”weightmeasurement100820151028”>
       <rdf:type rdf:resource=“&po;WeightMeasurement”/>
         <po : Measures>Mary Taylor</po : Measures>
         <po : Date >10:08:2015</po:Uses>
          <po : Time >10:28</po:Time>
          <po : Value >68.7</po:Value>
      </rdf : Description>
 </rdf:RDF>
```

Fig. 7. An instance of the Welfare Ontology in RDF.

5. Conclusion

Smart home cover many fields of technology including lighting, heating, ventilation, air conditioning, entertainment and home security. There are also various kinds of smart home systems focusing on different fields, each having their own user interfaces and data repositories. Yet, there are a lot of services that can only be produced by the interoperation of these systems.

The notion of smart data has a key role in system interoperation and information integration. In order to enable information sharing and exchange we have developed the Smart Home Ontology, which gives semantics for the data that are exchanged by the systems and devices in a smart home. In addition, we have exploited the principles of the Linked Data in order to integrate smart homes´ data with other external data sources. In this way we can also exploit the ontologies of these data sources, which in turn increase the usability of smart home systems. That is, i.e., by functioning together we can achieve outcomes that would not be obtainable by functioning independently.

In our smart home research we have restricted ourselves on health monitoring. The starting point for this work was our observation that smart home monitoring data (including a variety of sensors related to fitness) and PHR’s data should be analyzed as a whole. Thereby we can find out, for example, the dependencies between the training data and health data. Our argument is that these kinds of dependencies are of prime importance in coaching training as well as in designing patient care pathways.

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